CP violation in the lepton flavor violating interactions $\mu \rightarrow e\gamma$ and $\tau \rightarrow \mu\gamma$

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(Received 10 July 2001; published 8 November 2001)

We calculate the possible CP violating asymmetries for lepton flavor violating decays $\mu \rightarrow e\gamma$ and $\tau \rightarrow \mu\gamma$. Our predictions depend on the chosen new model independent contribution. The result of the measurements of such asymmetries for these decays will provide valuable information about the physics beyond the standard model.

DOI: 10.1103/PhysRevD.64.115005 PACS number(s): 12.60.Fr, 13.10.+q, 13.38.Dg

I. INTRODUCTION

Lepton flavor violating (LFV) interactions are among the most promising candidates to understand the physics beyond the standard model (SM). The improvement of their experimental measurements forces us to make more elaborate theoretical calculations and to determine the unknown parameters existing in the models used. $\mu \rightarrow e\gamma$ and $\tau \rightarrow \mu\gamma$ decays are the examples for the LFV decays and the current limits for their branching ratios (BR) are 1.2×10^{-11} [1] and 1.1×10^{-6} [2], respectively.

LFV interactions have been analyzed in different models in the literature. They were studied in a model independent way in [3], in the framework of model III type two-Higgs-doublet model (2HDM) [4], and in supersymmetric models [5–16]. Recently, the electromagnetic suppression of the decay rate of $\mu \rightarrow e\gamma$ has been predicted in [17]. Furthermore, the processes $\tau \rightarrow \mu\gamma$ and $\mu \rightarrow e\gamma$ have been studied as probes of neutrino mass models in [18].

LFV processes do not exist in the SM if the Cabibbo-Kobayashi-Maskawa- (CKM-) type matrix in the leptonic sector vanishes and this stimulates one to go beyond the standard model. The general two Higgs doublet model, the so-called model III, permits such interactions, which appear at least at the loop level, with the internal mediating neutral Higgs bosons h_0 and A_0. Note that, in this case, there is no charged flavor changing (FC) interaction. There are a large number of free parameters and their strength can be determined by the experimental data. The choice of complex Yukawa couplings causes the CP violating effects, which can also provide comprehensive information in the determination of the free parameters of various theoretical models. The nonzero electric dipole moments (EDM) of the elementary particles are a sign of such violations.

In this work, we study the possiblity of CP asymmetry A_{CP} of decays $\mu \rightarrow e\gamma$ and $\tau \rightarrow \mu\gamma$ in model III. Even if the Yukawa couplings are taken as complex, in general, model III does not ensure CP asymmetry for the decays under consideration. However, by correcting the decay rates of these processes with the additional complex contribution, which may come from the physics beyond model III, a measurable A_{CP} can be obtained. Here, we assume that the complexity of the new contribution is not due to the Yukawa type couplings, but probably to the radiative corrections, in this model. The multi-Higgs doublet model with more than two Higgs doublets is the possible candidate for such models. With the choice of real Yukawa couplings, except the ones related with the second Higgs doublet, it would be possible to get a nonzero A_{CP}. Therefore, A_{CP}, in the decays under consideration, can be the evidence of the existence of the physics beyond the SM. Furthermore, this physical quantity is informative in the determination of the type of the new physics and it is sensitive to the new free parameters in the model. The forthcoming experimental measurements of possible A_{CP} for both processes can give strong clues about the new physics effects beyond the SM.

The paper is organized as follows: In Sec. II, we present the possible CP violating asymmetry for LFV decays $\mu \rightarrow e\gamma$ and $\tau \rightarrow \mu\gamma$. Section III is devoted to discussion and our conclusions.

II. *CP* VIOLATION IN LFV INTERACTIONS $\mu \rightarrow e\gamma$ AND $\tau \rightarrow \mu\gamma$

The extension of the standard model (SM) with the additional Higgs doublet brings a possibility to create FC neutral currents (FCNC) at the tree level. The introduced *ad hoc* discrete symmetry in the Yukawa Lagrangian protects those FCNC currents and so-called model I and II type 2HDM is obtained [19]. If this symmetry is not considered, FCNC at the tree level is allowed. The Yukawa interaction for the leptonic sector in model III is

$$\mathcal{L}_Y = \eta^E_{ij}\overline{l}_{iL}\phi_1 E_{jR} + \xi^E_{ij}\overline{l}_{iL}\phi_2 E_{jR} + \text{H.c.}, \tag{1}$$

where i,j are family indices of leptons, L and R denote chiral projections $L(R) = 1/2(1 \mp \gamma_5)$, ϕ_i for $i = 1,2$, are the two scalar doublets, and l_{iL} and E_{jR} are lepton doublets and singlets, respectively. Here ϕ_1 and ϕ_2 are chosen as

$$\phi_1 = \frac{1}{\sqrt{2}}\left[\begin{pmatrix} 0 \\ v + H^0 \end{pmatrix} + \begin{pmatrix} \sqrt{2}\chi^+ \\ i\chi^0 \end{pmatrix}\right]; \phi_2 = \frac{1}{\sqrt{2}}\begin{pmatrix} \sqrt{2}H^+ \\ H_1 + iH_2 \end{pmatrix}, \tag{2}$$

and the vacuum expectation values are

$$\langle\phi_1\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v \end{pmatrix}; \langle\phi_2\rangle = 0. \tag{3}$$

With this choice, the SM particles can be collected in the first doublet and the new particles in the second one. Here the

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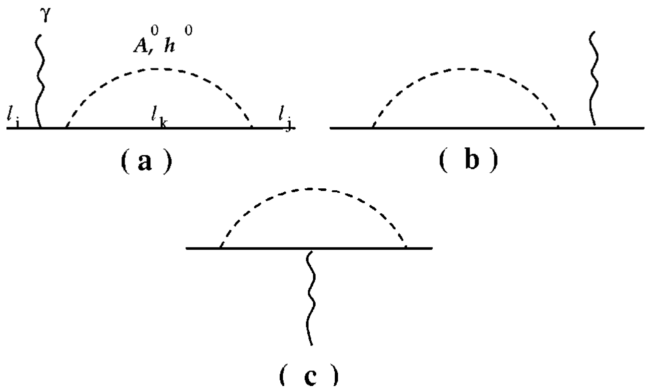

FIG. 1. One-loop diagrams contribute to the LFV decays $l_i \to l_j \gamma$ with $i \neq j$. The solid line corresponds to the lepton, the curly line to the electromagnetic field, and the dashed line to the fields h_0 and A_0. Here l_k denotes the leptons e, μ, τ.

bosons H_1 and H_2 are the neutral CP even h^0 and CP odd A^0, respectively, since there is no mixing between CP even neutral Higgs bosons H^0 and h^0 at the tree level. Furthermore, only the Yukawa couplings ξ^E_{ij} are responsible for the physics beyond the SM. In the case where both doublets develop vacuum expectation values, there would be mixing between the CP even neutral Higgs bosons H^0 and h^0 and this increases the number of free parameters, namely, the mixing angle α appears.

The part that produces FCNC (at the tree level) is

$$\mathcal{L}_{Y,FC} = \xi^E_{ij} \bar{l}_{iL} \phi_2 E_{jR} + \text{H.c.} \tag{4}$$

The Yukawa matrices ξ^E_{ij} have, in general, complex entries. Note that in the following we replace ξ^E with ξ^E_N where "N" denotes the word "neutral."

Now, let us consider the lepton number violating process $\mu \to e\gamma$. Here, we expect that the main contribution to this decay comes from the neutral Higgs bosons, namely, h_0 and A_0, in the leptonic sector of model III (see Fig. 1). Using the on-shell renormalization scheme the self-energy diagrams vanish and only the vertex diagram [Fig. 1(c)] contributes. By taking τ lepton for the internal line, the decay width Γ becomes [20]

$$\Gamma(\mu \to e\gamma) = c_1(|A_1|^2 + |A_2|^2), \tag{5}$$

where

$$A_1 = Q_\tau \frac{1}{8\, m_\mu m_\tau} \bar{\xi}^E_{N,\tau e} \bar{\xi}^E_{N,\tau\mu} [F_1(y_{h_0}) - F_1(y_{A_0})],$$
$$A_2 = Q_\tau \frac{1}{8\, m_\mu m_\tau} \bar{\xi}^{E*}_{N,e\tau} \bar{\xi}^{E*}_{N,\mu\tau} [F_1(y_{h_0}) - F_1(y_{A_0})], \tag{6}$$

$c_1 = G_F^2 \alpha_{em} m_\mu^5 / 32\pi^4$ and the function $F_1(w)$ reads

$$F_1(w) = \frac{w(3 - 4\,w + w^2 + 2\ln w)}{(-1+w)^3}, \tag{7}$$

with $y_H = m_\tau^2/m_H^2$. In Eq. (6), $\bar{\xi}^E_{N,ij}$ is defined as $\xi^E_{N,ij} = \sqrt{4\, G_F/\sqrt{2}}\,\bar{\xi}^E_{N,ij}$, the amplitudes A_1 and A_2 have right and left chirality, respectively, and $Q_\tau = -\frac{1}{3}$. In our calculations we ignore the contributions coming from internal μ and e leptons, respecting our assumption on the Yukawa couplings (see the Discussion).

At this stage, we calculate the CP asymmetry A_{CP} of the process $\mu \to e\gamma$, given by the expression

$$A_{CP} = \frac{\Gamma - \bar{\Gamma}}{\Gamma + \bar{\Gamma}}, \tag{8}$$

where $\bar{\Gamma}$ is the decay width for the CP conjugate process. However, in the framework of model III, A_{CP} vanishes and one needs an extra quantity to switch on the CP asymmetry. Therefore, we assume that there is an additional small and complex contribution χ due to the physics beyond model III such that the factor $\bar{\xi}^E_{N,\tau e}\, \bar{\xi}^E_{N,\tau\mu}\, [F_1(y_{h_0}) - F_1(y_{A_0})]$ is corrected as

$$\bar{\xi}^E_{N,\tau e} \bar{\xi}^E_{N,\tau\mu} [F_1(y_{h_0}) - F_1(y_{A_0})] + \chi.$$

Further, we force that the complexity of χ comes from the possible radiative corrections but not from the Yukawa type couplings, in the model beyond model III. This choice of χ brings a nonzero CP violation for the process $\mu \to e\gamma$:

$$A_{\mathrm{CP}} = 2 \frac{|\bar{\xi}^E_{N,\tau e} \bar{\xi}^E_{N,\tau\mu}| [F_1(y_{h_0}) - F_1(y_{A_0})] |\chi| \sin\theta_\chi \sin(\theta_{\tau e} + \theta_{\tau\mu})}{\Phi}, \tag{9}$$

where

$$\Phi = |\bar{\xi}^E_{N,\tau e} \bar{\xi}^E_{N,\tau\mu}|^2 [F_1(y_{h_0}) - F_1(y_{A_0})]^2 + |\chi|^2 + 2|\bar{\xi}^E_{N,\tau e} \bar{\xi}^E_{N,\tau\mu}| [F_1(y_{h_0}) - F_1(y_{A_0})] |\chi| \cos\theta_\chi \times \cos(\theta_{\tau e} + \theta_{\tau\mu}) \tag{10}$$

with $\chi = e^{i\,\theta_\chi}|\chi|$, $\bar{\xi}^E_{N,\tau e} = e^{i\,\theta_{\tau e}}|\bar{\xi}^E_{N,\tau e}|$, and $\bar{\xi}^E_{N,\tau\mu} = e^{i\,\theta_{\tau\mu}}|\bar{\xi}^E_{N,\tau\mu}|$. Of course, the amount of A_{CP} produced depends on the amount of new quantity introduced; however, even a small contribution may bring a measurable A_{CP} for this process.

At this stage, we introduce a model beyond model III so that the generation of complex parameter χ can be illustrated: The multi-Higgs doublet model, which contains more than two Higgs doublets in the Higgs sector, can be one of the candidates. The choice of three Higgs doublets brings new Yukawa couplings, which are responsible with the interactions between new Higgs particles and the fermions. The Yukawa Lagrangian in the three-Higgs-doublet model (3HDM) reads

$$\mathcal{L}_Y = \eta_{ij}^E \overline{l}_{iL} \phi_1 E_{jR} + \xi_{ij}^E \overline{l}_{iL} \phi_2 E_{jR} + \rho_{ij}^E \overline{l}_{iL} \phi_3 E_{jR} + \text{H.c.}, \tag{11}$$

where ρ_{ij}^E is the new coupling and ϕ_3 can be chosen as

$$\phi_3 = \frac{1}{\sqrt{2}} \begin{pmatrix} \sqrt{2} F^+ \\ H_3 + i H_4 \end{pmatrix}, \tag{12}$$

with vanishing vacuum expectation value. The fields F^+ and $H_3(H_4)$ represent the new charged and CP even (odd) Higgs particles, respectively. Note that the other Yukawa couplings and Higgs particles in Eq. (11) are the ones existing in model III. Now, we choose the additional Yukawa couplings ρ_{ij}^E real and take into account the radiative corrections to the contributions of the third Higgs doublet for the $\mu \to e \gamma$ decay. Here the complex part may come from the radiative corrections but not from the new Yukawa couplings. We can take this complex contribution as a source for the additional part χ [see Eqs. (9) and (10)]. The difficulty that arises in this model is the increase in the number of free parameters, namely, masses of new Higgs particles $m_{F^\pm}$, m_{H_3}, m_{H_4} and the new Yukawa couplings ρ_{ij}^E. However, the overall uncertainty coming from these free parameters lies in the contribution χ and it can be overcome by the possible future measurement of the CP violation for the decay under consideration.

Now, we would like to discuss the similar analysis for another LFV decay, $\tau \to \mu \gamma$. The decay width for this process is calculated by taking only the τ lepton as an internal one [20] and it reads as

$$\Gamma(\tau \to \mu \gamma) = c_2 (|B_1|^2 + |B_2|^2), \tag{13}$$

where

$$\begin{aligned} B_1 &= Q_\tau \frac{1}{48\, m_\mu m_\tau} \overline{\xi}^E_{N,\tau\mu} \{ \overline{\xi}^{E*}_{N,\tau\tau} [G_1(y_{h_0}) + G_1(y_{A_0})] \\ &\quad + 6 \overline{\xi}^E_{N,\tau\tau} [F_1(y_{h_0}) - F_1(y_{A_0})]\}, \\ B_2 &= Q_\tau \frac{1}{48\, m_\mu\, m_\tau} \overline{\xi}^{E*}_{N,\mu\tau} \{ \overline{\xi}^E_{N,\tau\tau} [G_1(y_{h_0}) + G_1(y_{A_0})] \\ &\quad + 6 \overline{\xi}^{E*}_{N,\tau\tau} [F_1(y_{h_0}) - F_1(y_{A_0})]\}, \end{aligned} \tag{14}$$

and $c_2 = G_F^2 \alpha_{em} m_\tau^5 / 32\pi^4$. Here the amplitudes B_1 and B_2 have right and left chirality, respectively. The function $F_1(w)$ is given in Eq. (7) and $G_1(w)$ is

$$G_1(w) = \frac{w(2 + 3\, w - 6\, w^2 + w^3 + 6\, w \ln w)}{(-1 + w)^4}.$$

A_{CP} in this process vanishes in model III, similar to the one in the decay $\mu \to e \gamma$ and we will follow the same procedure given above. By correcting the combination $\overline{\xi}^E_{N,\tau\mu} (\overline{\xi}^{E*}_{N,\tau\tau} [G_1(y_{h_0}) + G_1(y_{A_0})] + 6\, \overline{\xi}^E_{N,\tau\tau} [F_1(y_{h_0}) - F_1(y_{A_0})])$ with the additional small and complex quantity ρ due to the physics beyond model III as

$$\begin{aligned} &\overline{\xi}^E_{N,\tau\mu} (\overline{\xi}^{E*}_{N,\tau\tau} [G_1(y_{h_0}) + G_1(y_{A_0})] \\ &\quad + 6\, \overline{\xi}^E_{N,\tau\tau} [F_1(y_{h_0}) - F_1(y_{A_0})]) + \rho, \end{aligned}$$

we get

$$A_{CP} = \frac{\Lambda}{\Omega}, \tag{15}$$

where

$$\begin{aligned} \Lambda &= 2 |\overline{\xi}^E_{N,\tau\mu} \overline{\xi}^{E*}_{N,\tau\tau}| |\rho| \sin\theta_\rho \{ \sin(\theta_{\tau\mu} - \theta_{\tau\tau}) [G_1(y_{h_0}) \\ &\quad + G_1(y_{A_0})] + 6 \sin(\theta_{\tau\mu} + \theta_{\tau\tau}) [F_1(y_{h_0}) - F_1(y_{A_0})]\}, \end{aligned} \tag{16}$$

and

$$\begin{aligned} \Omega &= |\overline{\xi}^E_{N,\tau\mu} \overline{\xi}^{E*}_{N,\tau\tau}|^2 ([G_1(y_{h_0}) + G_1(y_{A_0})]^2 + 36 [F_1(y_{h_0}) \\ &\quad - F_1(y_{A_0})]^2) + |\rho|^2 + 12 |\overline{\xi}^E_{N,\tau\mu} \overline{\xi}^{E*}_{N,\tau\tau}|^2 [F_1(y_{h_0}) \\ &\quad - F_1(y_{A_0})][G_1(y_{h_0}) + G_1(y_{A_0})] \cos 2\,\theta_{\tau\tau} \\ &\quad + 2 |\overline{\xi}^E_{N,\tau\mu} \overline{\xi}^{E*}_{N,\tau\tau}| |\rho| [G_1(y_{h_0}) + G_1(y_{A_0})] \cos\theta_\rho \\ &\quad \times \cos(\theta_{\tau\mu} - \theta_{\tau\tau}) + 12 |\overline{\xi}^E_{N,\tau\mu} \overline{\xi}^{E*}_{N,\tau\tau}| |\rho| [F_1(y_{h_0}) \\ &\quad + F_1(y_{A_0})] \cos\theta_\rho \cos(\theta_{\tau\mu} + \theta_{\tau\tau}), \end{aligned} \tag{17}$$

with $\rho = e^{i\,\theta_\rho} |\rho|$ and $\overline{\xi}^E_{N,\tau\tau} = e^{i\,\theta_{\tau\tau}} |\overline{\xi}^E_{N,\tau\tau}|$. Similar to the process $\mu \to e \gamma$, the amount of A_{CP} strongly depends on the new quantity introduced and a small contribution may bring measurable A_{CP} for this process also.

III. DISCUSSION

In the case of vanishing charged interactions, with the assumption that a CKM type matrix in the leptonic sector does not exist, LFV interactions are possible in the one loop, due to neutral Higgs bosons h^0 and A^0, in the framework of model III. In general, the Yukawa couplings $\overline{\xi}^E_{N,ij}, i,j = e, \mu, \tau$ appearing in the expressions are complex and they ensure nonzero lepton EDM. However, this scenario is not enough to get a CP violating asymmetry in the LFV pro-

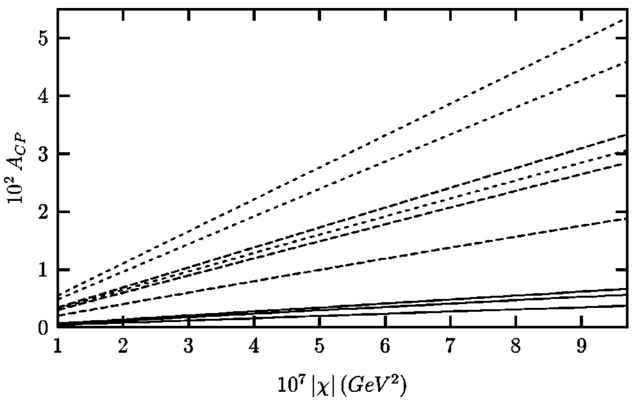

FIG. 2. A_{CP} of the process $\mu \to e\gamma$ as a function of $|\chi|$ for $\sin\theta_{\tau\mu}=0.5$, $m_{h^0}=85$ GeV, and $m_{A^0}=95$ GeV. Here, the solid lines show the case where $\sin\theta_\chi=0.1$ and they correspond to $\sin\theta_{\tau e}$ values 0.1, 0.5, and 0.8 in the order from the lower one to the upper. Similarly, the dashed (small dashed) lines represent the case where $\sin\theta_\chi=0.5$ ($\sin\theta_\chi=0.8$).

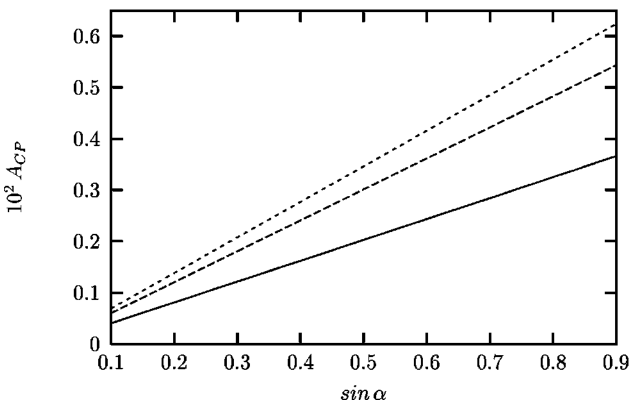

FIG. 3. $A_{\rm CP}$ of the process $\mu \to e\gamma$ as a function of $\sin\theta_\chi$ for $|\chi|=10^{-7}$ (GeV^2), $\sin\theta_{\tau e}=0.5$, $m_{h^0}=85$ GeV, and $m_{A^0}=95$ GeV. Here, the solid line coresponds to $\sin\theta_{\tau\mu}=0.1$, dashed line to $\sin\theta_{\tau\mu}=0.5$, and small dashed line to $\sin\theta_{\tau\mu}=0.8$.

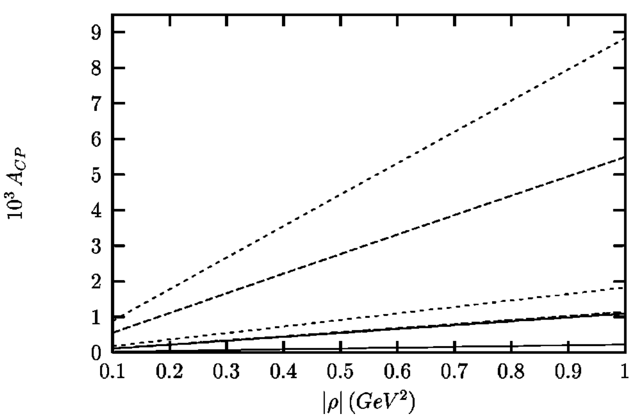

FIG. 4. A_{CP} of the process $\tau \to \mu\gamma$ as a function of $|\rho|$ for $\bar{\xi}^E_{N,\tau\tau}=100$ GeV, $\sin\theta_\rho=0.1$, $\sin\theta_{\tau\mu}=0.5$, $m_{h^0}=85$ GeV, and $m_{A^0}=95$ GeV. Here, A_{CP} is restricted between solid lines for $\sin\theta_{\tau\tau}=0.1$, dashed lines for $\sin\theta_{\tau\tau}=0.5$, and small dashed lines for $\sin\theta_{\tau\tau}=0.8$.

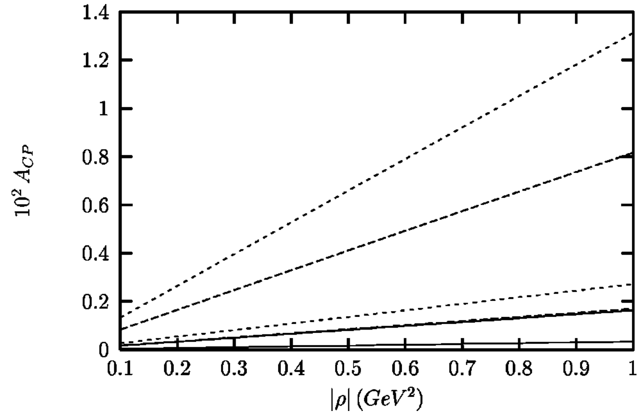

FIG. 5. The same as Fig. 4 but for $\sin\theta_\rho=0.5$.

cesses, $\mu \to e\gamma$ and $\tau \to \mu\gamma$. To obtain such asymmetry, we introduce a small model independent correction term to the decay width with the following features:

(i) this term is due to the physics beyond model III;

(ii) it is complex and the complexity does not come from the Yukawa type couplings.

Note that we introduced the multi-Higgs doublet model, which contains more than two Higgs doublets with complex Yukawa couplings due to only the second doublet (see Sec. II).

The additional contributions respecting the above conditions bring nonzero A_{CP} to both processes under consideration. However, this extra quantity is completely unknown and the number of parameters, namely, complex Yukawa couplings and a new model independent quantity, increases in the numerical calculations. To solve this problem, first, we assume that the Yukawa couplings $\bar{\xi}^E_{N,ij}$, $i,j=e,\mu$, are small compared to $\bar{\xi}^E_{N,\tau i} i=e,\mu,\tau$ since the strength of them is related with the masses of leptons denoted by their indices, similar to the Cheng-Sher scenerio [21]. Further, we take $\bar{\xi}^E_{N,ij}$ symmetric with respect to the indices i and j. Therefore only the combination $\bar{\xi}^E_{N,\tau\mu}\bar{\xi}^E_{N,\tau e}$ (the couplings $\bar{\xi}^E_{N,\tau\tau}$ and $\bar{\xi}^E_{N,\tau\mu}$) for the process $\mu \to e\gamma$ ($\tau \to \mu\gamma$) plays the main role in our analysis. $\bar{\xi}^E_{N,\tau\mu}\bar{\xi}^E_{N,\tau e}$ can be restricted using the experimental upper limit of the BR of the process $\mu \to e\gamma$ [1]:

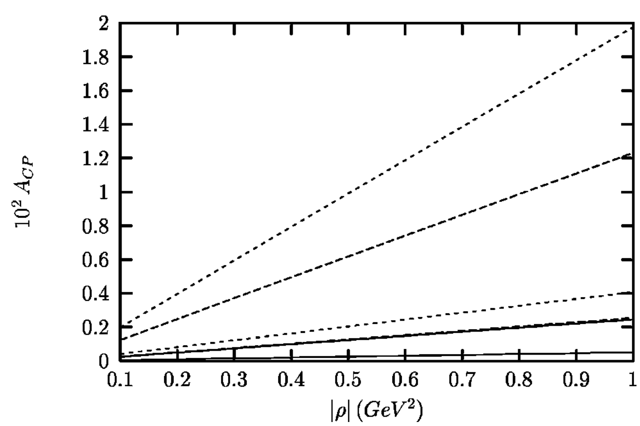

FIG. 6. The same as Fig. 4 but for $\sin\theta_\rho=0.8$.

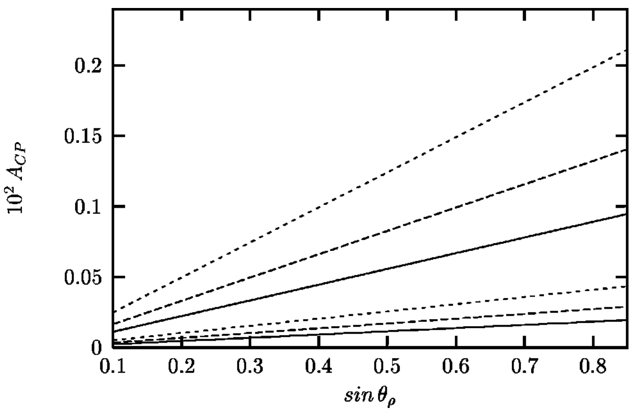

FIG. 7. A_{CP} of the process $\tau\to\mu\gamma$ as a function of $\sin\theta_\rho$ for $|\rho|=0.1$ (GeV^2), $\sin\theta_{\tau\mu}=0.5$, $m_{h^0}=85$ GeV, and $m_{A^0}=95$ GeV. Here, A_{CP} is restricted between solid lines for $\sin\theta_{\tau\tau}=0.1$, dashed lines for $\sin\theta_{\tau\tau}=0.5$, and small dashed lines for $\sin\theta_{\tau\tau}=0.8$.

$$\mathrm{BR}(\mu\to e\gamma)<1.2\times10^{-11}. \tag{18}$$

(see [20] for details). Here, we do not take the contribution of an additional part coming from the physics beyond model III since we assume that its effect on the constraint region is sufficiently small. Note that we take the additional contribution $|\chi|$ as two orders smaller compared to $\bar{\xi}^E_{N,\tau e}\bar{\xi}^E_{N,\tau\mu}[F_1(y_{h_0})-F_1(y_{A_0})]$.

For the process $\tau\to\mu\gamma$, the coupling $\bar{\xi}^E_{N,\tau\mu}$ is restricted using the experimental upper and lower limits of μ-lepton EDM ([22]),

$$0.3\times10^{-19}e\ \mathrm{cm}<d_\mu<7.1\times10^{-19}e\ \mathrm{cm} \tag{19}$$

(see [20] for details) and we do not use any constraint for the coupling $\bar{\xi}^E_{N,\tau\tau}$. For this decay, the additional contribution $|\rho|$ is taken as two orders smaller compared to $\bar{\xi}^E_{N,\tau\mu}\{\bar{\xi}^{E*}_{N,\tau\tau}[G_1(y_{h_0})+G_1(y_{A_0})]+6\bar{\xi}^E_{N,\tau\tau}[F_1(y_{h_0})-F_1(y_{A_0})]\}$, similar to the previous process.

Figure 2 represents the new quantity $|\chi|$ dependence of A_{CP} for $\sin\theta_{\tau\mu}=0.5$, $m_{h^0}=85$ GeV and $m_{A^0}=95$ GeV. Here the solid lines show the case where $\sin\theta_\chi=0.1$ and they correspond to $\sin\theta_{\tau e}$ values 0.1, 0.5, and 0.8 in the order from the lower one to the upper. Similarly the dashed (small dashed) lines represents the case where $\sin\theta_\chi=0.5$ ($\sin\theta_\chi=0.8$). Choosing $|\chi|$ at the order of $10^{-7}(\mathrm{GeV}^2)$, A_{CP} for the process can be at the order of the magnitude 10^{-2}. As shown in this figure, A_{CP} is sensitive to the *CP* parameters $\sin\theta_{\tau\mu}$, $\sin\theta_{\tau e}$ and obviously to $\sin\theta_\chi$.

In Fig. 3 we present $\sin\theta_\chi$ dependence of A_{CP} for $|\chi|=10^{-7}(\mathrm{GeV}^2)$, $\sin\theta_{\tau e}=0.5$, $m_{h^0}=85$ GeV, and $m_{A^0}=95$ GeV. Here, the solid line coresponds to $\sin\theta_{\tau\mu}=0.1$, dashed line to $\sin\theta_{\tau\mu}=0.5$, and small dashed line to $\sin\theta_{\tau\mu}=0.8$. A_{CP} increases with increasing values of the parameters $\sin\theta_\chi$, $\sin\theta_{\tau e}$, and $\sin\theta_{\tau\mu}$.

Now we would like to show our results for the A_{CP} of the process $\tau\to\mu\gamma$ in the series of Figs. 4–8. Figure 4 is devoted to the new quantity $|\rho|$ dependence of A_{CP} for $\bar{\xi}^E_{N,\tau\tau}=100$ GeV, $\sin\theta_\rho=0.1$, $\sin\theta_{\tau\mu}=0.5$, $m_{h^0}=85$ GeV, and $m_{A^0}=95$ GeV. Here, A_{CP} is restricted between solid lines for $\sin\theta_{\tau\tau}=0.1$, dashed lines for $\sin\theta_{\tau\tau}=0.5$, and small dashed lines for $\sin\theta_{\tau\tau}=0.8$. Note that the upper and lower bounds for A_{CP} are due to the constraint of $\bar{\xi}^E_{N,\tau\mu}$ coming from the experimental limits of μ-lepton EDM. A_{CP} for this process is of the order of magnitude 10^{-3}. However, the increasing values of $\sin\theta_\rho$ enhances it almost one order as seen in Figs. 5 and 6, where they correspond to $\sin\theta_\rho$ values 0.5 and 0.8, respectively. The strong sensitivity of A_{CP} to the parameter $\sin\theta_\rho$ is shown in Fig. 7. In this figure, we present $\sin\theta_\rho$ dependence of A_{CP} for $|\rho|=0.1(\mathrm{GeV}^2)$, $\sin\theta_{\tau\mu}=0.5$, $m_{h^0}=85$ GeV, and $m_{A^0}=95$ GeV. Here, A_{CP} is restricted between solid lines for $\sin\theta_{\tau\tau}=0.1$, dashed lines for $\sin\theta_{\tau\tau}=0.5$, and small dashed lines for $\sin\theta_{\tau\tau}=0.8$. These figures show that the restriction region for A_{CP} becomes broader with increasing values of $\sin\theta_{\tau\tau}$. The same behavior appears when $\sin\theta_{\tau\mu}$ increases also.

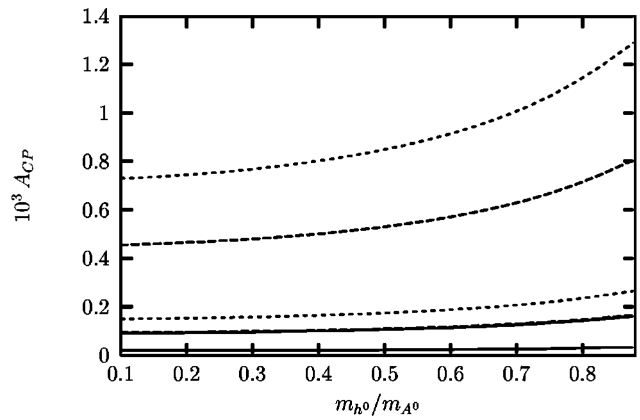

FIG. 8. A_{CP} of the process $\tau\to\mu\gamma$ as a function of the mass ratio m_{h^0}/m_{A^0} for $\bar{\xi}^E_{\tau\tau}=100$ GeV, $\sin\theta_{\tau\mu}=\sin\theta_{\tau\tau}=0.5$, $|\rho|=0.1$ (GeV^2), and $m_{h^0}=85$ GeV.

Finally, we study the mass ratio m_{h^0}/m_{A^0} dependence of A_{CP} for the fixed values of $\sin\theta_{\tau\mu}=\sin\theta_{\tau\tau}=0.5$, $|\rho|=0.1$ (GeV^2), and $m_{h^0}=85$ GeV in Fig. 8. Here A_{CP} is restricted between solid lines for $\sin\theta_\rho=0.1$, dashed lines for $\sin\theta_\rho=0.5$, and small dashed lines for $\sin\theta_\rho=0.8$. It is observed that A_{CP} increases when the masses of neutral Higgs bosons are near to degeneracy. This enhancement is large for large values of $\sin\theta_\rho$.

As a result, it is possible to get a measurable A_{CP} for the LFV interactions $\mu\to e\gamma$ and $\tau\to\mu\gamma$ if there exists an additional small and complex contribution coming from the physics beyond model III. Here, the complexity of the new contribution should not be due to the Yukawa type couplings, but comes from radiative corrections. With the reliable experimental measurements of such asymmetries, it would be possible to test the new contributions and the corresponding physics.

ACKNOWLEDGMENT

This work was supported by the Turkish Academy of Sciences (TUBA-GEBIP).

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